(4)

ARL-PROP-TM-439

AR-004-515

AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Propulsion Technical Memorandum 439

IFDIS - AN EXPERT SYSTEM FOR DIAGNOSIS OF FAILURES IN JET AIRCRAFT ENGINES (U)

by

M.D. Larkin

D. A. Frith
A.S. Findlay

Approved for public release

JANUARY 1987

(A)

AR-004-515

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORY

Propulsion Technical Memorandum 439

IFDIS - AN EXPERT SYSTEM FOR DIAGNOSIS OF FAILURES IN JET AIRCRAFT ENGINES

by

M.D. Larkin
Deakin University

D.A. Frith
A.S. Finlay
Aeronautical Research Laboratory

SUMMARY

IFDIS (Interactive Fault Diagnosis and Isolation System) is being developed to aid in the isolation of faults in the F404 jet engines that are installed in the F/A-18 fighters. Existing documentation supporting troubleshooting for these engines is inflexible in the level of sophistication expected of the user and it does not explicitly use the reasoning with uncertain information which is inherent in human troubleshooting. Data, which is required for troubleshooting the F404, is currently or potentially available for computer processing from a number of sources. IFDIS will assist maintenance personnel by providing on-line access to relevant information and will perform much of the tedious interpretation of the available data. The expert knowledge embodied in some of the existing maintenance manuals has been re-expressed in a format that serves as the basis for the knowledge-base for an expert system. Expert system techniques have been employed because they offer benefits of perspicuity, they can be developed incrementally and can cope with imprecise data. IFDIS is currently based on EMYCIN but will be reimplemented using a commercial expert system shell in the near future.

DSTO ARL
MELBOURNE

POSTAL ADDRESS: **Director, Aeronautical Research Laboratory, P.O. Box 4331, Melbourne, Victoria, 3001, Australia**

TABLE OF CONTENTS

Chapter 1

Introduction

IFDIS is designed to assist in the diagnosis and isolation of faults in the F404-GE-400 turbofan engines, two of which are installed in each of the F/A-18 fighter aircraft. Problems with the engines are usually brought to the attention of the maintenance crew via a report by the pilot and/or by the appearance of a warning code on the Maintenance Monitor Panel (MMP) indicator that is inspected after the aircraft returns from a sortie. A wide variety of codes can be displayed on the MMP indicator relating to the aircraft's systems such as radars, weapons etc. with only a subset being directly attributable to problems with the engines or associated sensors. When a problem is reported by the pilot, an EE500 form is completed that describes the symptoms of the failure and the situation in which the failure occurred.

Maintenance on the engines is performed at three main levels; Organisational level (O-Level) , Intermediate level (I-level) and Depot level. O-level maintenance consists of troubleshooting the engine to isolate the problem to a component which can be replaced with the engine installed in the aircraft. This replacement policy is taken to the extreme of replacing the entire engine if the problem cannot be isolated to a component which can be replaced with the engine installed. I-level maintenance is concerned with repairing modules which which have been identified as faulty during O-level procedures and with troubleshooting of entire engines if it has not been possible to identify the problem at O-level. Depot level maintenance is focussed on the repair of components which have been found to be faulty at O-level and I-level. IFDIS is currently concerned with application to O-level maintenance but may be extended to cover I-level in due course.

The F/A-18 is a recent addition to the RAAF inventory. It is the first RAAF aircraft to use the F404 and consequently no Australian personnel have extended experience with these engines. Training courses have been attended in the US and Australia that provide attendees with an under standing of the principles of operation of the engines. Due to the lack of extensive experience with this particular engine, personnel have not had the opportunity to develop formulaic approaches to particular types of failures which would result from having investigated a number of similar failures.

The basic troubleshooting documentation, the Work Package documentation (i.e. WP's) is expressed in the form of binary fault tree tables (see fig. 1 for example). A number of questions are posed and can be answered Yes or No. These answers are used to trace through the binary tree by selecting the next question to be posed. While the order in which tests are to be performed is explicit in the WP's, the reason for the particular order chosen is not. Eventually, a recommendation for remedial action is made. These recommendations usually suggest either adjusting, servicing or replacing a component. The appropriate table in a WP is selected on the basis of indications of the initial symptom such as the specific MMF codes or descriptions of the engine's behaviour such as hot start.

The basic maintenance documentation (i.e. the WP's) is pitched at a level which is suitable for the most inexperienced maintenance people. More experienced people find the verbose step-by-step approach tiresome. A more appropriate form of assistance which is adaptable to a range of skill and experience levels is sought.

The volume of documentation which is provided with modern systems can be daunting. One estimate of the documentation relevant to the F/A-18 is 500,000 pages [5] and simply locating the relevant section of this documentation can be a difficult task. Some way to provide ready reference to this material is to be recommended. The example of the M.D system [5] where a large body of the relevant documentation has been analysed and cross-referenced so that it can be accessed via a computer using Expert Systems techniques (see later section) is illustrative of an approach which has proven valuable.

All the above considerations were important in deciding that a new method for the isolation, remedy and recording of faults should be considered. The next step was to decide what approach should be employed. Work reporting results of applying Expert Systems techniques to diagnosis problems indicated that the use of such techniques could prove fruitful.

Chapter 2

Expert Systems

Expert Systems utilise techniques developed by Artificial Intelligence researchers. A large collection of knowledge is compiled and applied to tasks which are generally regarded as requiring expertise when performed by a human. An Expert System is constructed by capturing the knowledge of one or more experts and encoding this knowledge in a form suitable for computer processing.

An expert system usually comprises the following components : inference engine , knowledge-base and user interface. Other taxonomies are presented by other workers but for the present purpose, the foregoing will suffice. The inference engine of the Expert System contains the procedure for the selection and application of knowledge from the knowledge-base. It has been claimed that it is possible to separate the inference engine from the knowledge-base so cleanly that one can have a number of knowledge-bases which can be manipulated by the same inference engine for widely varying application areas. Other workers disagree with this approach and recommend that the builder of the expert system start from a lower level and use a language such as Lisp or Prolog to construct an application-specific inference engine with any specialised reasoning strategies needed for the application being built in. For a consideration of the attributes required of a shell for the implementation of a more ambitious version of IFDIS, see the section titled 'An appropriate shell for IFDIS'. A number of frameworks for the construction of experts systems are available (e.g. KEE, S.1, ART). Such packages usually include a representation for knowledge, often via a rule-like formalism, and tools for entering, editing and modifying a knowledge-base. These pre-built packages are often referred to as expert system shells because they lack a knowledge-base for a specific application area. The user provides the knowledge-base.

There are usually a number of people filling different roles involved in the development of an Expert system for application to a particular problem area. The people involved in the development and use of an expert system are usually classed into the following categories : Domain Experts, knowledge Engineers and user. The domain expert or experts have acknowledged expertise in the problem area under consideration. The knowledge engineer has a good understanding of the techniques which are available for the construction of the expert system. The user is the person who will use the completed system as an aid in the completion of tasks in a problem environment.

A variety of knowledge elicitation strategies have been developed [14] but only two approaches will be considered here.

The oldest method is that of interviewing the Domain Expert to discover what conceptual entities and procedures are used to solve the problem. The Knowledge Engineer and the Domain Expert build a knowledge-base and test its ability to reach the correct conclusion for a set of examples from the problem. The knowledge-base is built by identifying entities which are reasoned about and also deriving causal and heuristic knowledge which is used to solve the problem. This knowledge is then placed in the knowledge base. If knowledge exists in a codified form, perhaps in manuals or textbooks, then such knowledge can be used to generate a knowledge-base that can be modified and extended with the assistance of domain experts.

The more recently developed method of inductive rule inference can also be used to construct a knowledge-base. The Domain Expert supplies a set of examples and the conclusion which should be reached for each example. An inductive inference is then performed on this set of examples and a rule is generated which will reach the correct conclusion for each example. This rule can then be used to reach conclusions about situations which arise in the field. Inductive inferencing can quickly build and modify a knowledge base once attributes which are to appear in the examples have been chosen. If the Expert System reaches an incorrect conclusion for a case then the knowledge-base can be extended to cope with the case by supplying the case as an extra example along with the correct conclusion. Rulemaster and Expert Ease are commercially available shells which provide this facility.

When the Domain Expert is satisfied that the Expert System is a reasonable representation of the expertise required, it is handed over to Users for evaluation. Often when a User is exercising the system , new problems not anticipated by the Domain Expert will arise and a new strategy will be specified to cope with the problem. Users of the system will also typically provide feedback on the acceptability of various aspects of the system and suggest changes which will make use of the system more comfortable and/or efficient.

Expert Systems can exhibit advantages over conventional programs in a number of respects. The expert's knowledge can be incorporated into the system in a form that explicitly displays the expert's reasoning and, if requested, can be presented to the user in a form which is likely to be understood. Typical results of the use of explanation facilities in Expert Systems can be found at points A and B in Appendix A. This differs from the conventional program where many of the assumptions and procedures underlying the solution to the problem are implicitly incorporated into the algorithm used to solve the problem and are not accessible to users of the program.

Techniques for reasoning with uncertain information have been developed to minimise problems that arise when the user does not know the answer to a question or when the user is not totally confident of the accuracy of the answer supplied. These techniques can also accommodate uncertainty in the knowledge provided by the domain expert. Such problems are typically not handled well by conventional programs.

The problems associated with the maintenance of large software artifacts are well known. The use of Expert System techniques can lead to less error-prone maintenance and enhancement of large systems. Software techniques have been developed to assist the Knowledge Engineer and Domain Expert in updating the knowledge-base by checking for conflicts and overlap between pieces of knowledge. Such facilities are extremely useful if not essential when updating large knowledge-bases.

The speed with which prototype expert systems can be developed can be of great benefit in areas where it is difficult if not impossible to specify the total solution to the problem at the first attempt. The Domain

Expert is able to interact with a Knowledge Engineer and the Expert System to rapidly refine the knowledge-base used by the Expert System. The availability of a concrete representation (i.e. the knowledge-base) of part of a problem-solving strategy has been found to assist Domain Experts in structuring their thoughts when extending the knowledge-base. It has also been noted that the task of expressing part of their knowledge in the form of a knowledge-base can have an indirect benefit of improving the Expert's appreciation of the problem domain.

A currently popular representation for knowledge is in the form of rules which express causal and heuristic knowledge which the Expert applies during the search for a solution to the problem. Typically, rules have the following format :

If condition
Then action

A collection of such rules is assembled along with some representation of the entities about which the expert system will be required to reason. For an example of an actual rule from IFDIS, refer to fig. 2. It is expected that experience with the system in operation will result in modifications being made to the certainty with which the system reaches conclusions. For example, the rule in fig. 2 may be modified to reach its conclusion with a lower certainty, perhaps 0.8 instead of 1.0.

Two primary inferencing strategies are commonly used to control the reasoning which the expert system undertakes. These are forward- and backward-chaining. Forward-chaining (also referred to as Data-driven) inferencing operates by collecting values for a range of entities and applying the rules in the knowledge-base to these entities. Backward chaining (or Goaldriven) inferencing operates by establishing a high-level goal (such as find faulty component) and then determining which rules can be used to help in the determination of this conclusion. This procedure is applied recursively until no further rules are applicable and the user is asked to supply a value for a particular entity (such as does the variable exhaust nozzle actuator operate smoothly ?).

Expert System techniques will enable assistance to be provided to maintenance personnel in a number of ways. Assistance at an appropriate level should be available to less experienced personnel enabling them to work on more routine diagnoses without needing to refer to a busy human expert. Access to appropriate documentation can be made quickly and conveniently available without the need to refer to indexes etc. in order to determine what information is relevant. The expert will have ready access to procedures for the diagnosis of rarely occuring faults which they may not have personally encountered.

Chapter 3

Previous work

A number of different approaches to diagnosis of failures within complex equipment are available . A number of previous attempts have been made in the application of Expert systems to diagnosis problems. The variety of domains in which the attempts have been made is wide: bacterial infections [3], selection of drilling mud [16], problems with automobiles [11], flight avionic systems [5], diesel-electric locomotives [15], electronic test equipment [22], signal-switching network equipment [18] etc. An excellent guide to the literature is provided by Buchanan [4]. Many of the reports on this work claim success for the limited problem domain to which they have been applied. A report commissioned by ARL on the appropriateness of expert systems techniques for application to the domain addressed by IFDIS commented favourably upon the proposal [12].

One of the earliest applications of expert systems approaches to diagnosis of failures in electromechanical equipment was CATS (Computer Aided Troubleshooting System) from General Electric [15]. This system was developed to aid in the repair of diesel-electric locomotives. Information from various manuals and knowledge of various experts in the diagnosis of problems with locomotives were combined and incorporated into the knowledge-base for an expert system that runs on a personal computer and which can access diagrams on video-disk of various components and specifications for use during repair of the locomotive. One of the benefits of having such a system was the reduction in the number of inappropriate, time-consuming and expensive tests which were undertaken by less experienced personnel who had access to this system. The CATS system is apparently now in routine use within General Electric .

Another example of work on improving support for maintenance is that of the M.D (Maintenance Diagnostician) system [5]. M.D is a system which can trouble-shoot the pitch-control channel of an F-15 flight control. The system can provide guidance on diagnosis and can access diagrams to assist maintenance personnel. The system was constructed to help the USAF reduce problems that arise as a consequence of having increasingly complex equipment to maintain while the skill-level of available maintenace personnel is declining. The system is based on an IBM-PC which can access a video disk which stores diagrams of parts, schematics of subsystems etc. The operator can request information on the location of a particular part if necessary and appropriate test equipment can be recommended where necessary. The knowledge base for M.D. was constructed by collating information from a number of relevant Technical Orders.

Chapter 4

Current work

Work is currently being undertaken at Deakin University under a Research Agreement with ARL. An experimental implementation of IFDIS has been constructed using the EMYCIN shell [21] on a DECSYSTEM-20. EMYCIN is based on the pioneering MYCIN system which addressed the medical problem of diagnosing bacterial infections. EMYCIN resulted from an attempt to remove all application-specific knowledge from MYCIN to obtain a domain independent knowledge-base construction environment along with a generally applicable inference engine. The rule entry and editing tools provided by EMYCIN include a mechanism for checking for consistency between rules as they are entered. A limited natural language interface capability is also incorporated in the EMYCIN shell. It has an explanation facility which can be used to investigate the reasoning strategy being used during the consultation. Users can use this facility to investigate why certain questions are being asked etc. EMYCIN is primarily a backward-chaining shell but forward-chaining rules can be incorporated for limited data-driven processing.

EMYCIN was initially chosen because of its low cost and its previous success in diagnostic problem domains. EMYCIN is most suited to tasks which can be expressed as problems of structured-selection. Structured-selection problems are those in which the possible solutions to the problem can be enumerated by the expert. A series of questions are then issued by the Expert System and answered by the user. Answers to successive questions are used to progressively reduce the size of the list of failures which could have resulted in the observed problem. One or more solutions that are not excluded by the answers given by the user are presented at the end of the consultation. In some cases, the proposed solutions or recommendations are then ranked in order of merit depending on the strength of the evidence supporting each conclusion.

Because of a lack of expertise in the construction of Expert Systems and the difficulties of obtaining further resources it was not feasible to start by writing a shell. The decision was made to gain experience in the practical aspects of knowledge-base construction and insights into the type of capability required for an Expert System for a full-scale IFDIS by experimenting with EMYCIN.

The approach taken so far to converting the knowledge encoded in the fault-tree tables has been roughly as outlined below. Further development will probably require intensive interaction with ground maintenance personnel and engineers expert in various aspects of the engine's operation. It is expected that such interaction will result in alterations to the procedures specified in the fault trees to better contend with the uncertainty inherent in some judgements that must be made during troubleshooting sessions.

To generate the first EMYCIN knowledge-base for IFDIS, work started with WP 005 00 which is concerned with start failures. WP 005 00 is divided into three tables, No Start, Hot Start and Stall Start. Each of the interrogatory questions in the WP was represented by a Parameter in EMYCIN e.g. question a. of WP 005 00 Table 1 is represented by a Parameter called FAN-COMPRESSOR-ROTATE. Rules were then written to ensure that the same sequence of questions was generated by IFDIS as is specified in the WP. It became necessary to introduce higher-level Parameters to the knowledge-base so that the number of premises in rules could be kept manageable. The specification of these extra Parameters was made difficult because of the concurrent threads of investigation which can be active at any one time. Deriving a name and description for the parameter was, in many situations, difficult because the intent of certain lines of reasoning was not immediately apparent. The initial EMYCIN knowledge-base has been extended to cover Table 1 of WP 007 00. The knowledge-base currently consists of approximately 100 rules using approximately 100 parameters.

EMYCIN has been reasonably successful for the section of the manuals so far analysed. The problems of encoding procedural knowledge have caused some difficulty however (see [1] for a consideration of this point). The quality of explanation generated from rules with a number of clauses in the premise that have been ordered for the sole purpose of forcing a particular order of evaluation are low (see fig. 3). The reason for the ordering of the premises in the rules is not explicit - e.g. no justification for the performance of the ground idle throttle test before the throttle off test is given in RULE066 (see A1 in Appendix A). EMYCIN provides a facility whereby text can be associated with a rule as a justification for the rule but this text is static and is not updated by the inference engine as the results of tests become known - a full justification of the rule for all situations in which it might be invoked would be cumbersome and extremely difficult to understand for rules with a large number of premises.. It was found to be necessary to introduce higher-level parameters/goals so that the consultation could be given more structure. For example, the parameter THROTTLE-OR-PUMP-PROBLEM was introduced to collect the results from five questions (i.e. questions g, h, i, w, and y in WP 005 00 Table 1). By the inclusion of higher-level parameters/goals, it became possible to specify rules of a strategic nature (e.g. check fuel supply, check electrical system) rather than rules which are a collection of tactics (e.g. check fuel filter, check fuel pump, ... , check yellow cable, check blue cable etc.). The identification of the strategies employed in the WP's has been difficult and will be examined later in the paper.

The knowledge representation capabilities of EMYCIN were barely adequate for the task but more flexibility would have been advantageous. The availability of a richer representation formalism, such as a flexible implementation of frames, and a more flexible inference engine would have enabled a better structuring of the knowledge-base. As mentioned before, the availability of a better method for the encoding of procedural knowledge would also have been advantageous. Refer to the later section entitled 'An appropriate shell for IFDIS' for further consideration of desired shell attributes.

In an attempt to impose some discernible structure on the consultation given by the expert system it has been necessary to introduce higher-level entities into the knowledge-base which depend on the results of a number of the questions which appear in the fault-tree provided within the work package documentation. As a consequence of the manner in which the fault-trees have been laid out, it is sometimes difficult to determine the reason for asking the questions in the order specified by the fault-tree. The reasoning appears to jump between investigations in support of various competing hypotheses as to what component is at fault. The sequence of tests might also be partially ordered by a consideration of the cost of performing the various tests. Limited use of experts has been made in an attempt to clarify some of the reasoning involved. A trip to the Williamtown base and discussions with some of the maintenance personnel there also helped to clarify some issues and suggested aspects of the system which required further investigation.

It is not known how the fault-tree tables were compiled. It seems at least possible that they were computer generated and optimised in some sense, perhaps to minimise the number of tests to be performed. Such optimisation may have contributed to the apparent opacity of some of the recommended procedures. Access to the reasoning which was behind the construction of the fault-trees would greatly enhance the quality of the knowledge-base upon which IFDIS is based.

It is essential to have domain experts available during the development of the knowledge-base to explain the reasoning underlying the fault trees. These experts MUST be able to answer questions quickly, and preferably from direct experience, since the delay in finding the answers to mundane questions by extensive reference to the documentation is intolerable. The hypothesis that the knowledge encoded in the WP's should have given the project a good start was partially correct. The availability of a large amount of information in this relatively easily digested form was an advantage during the initial construction of the knowledge-base. The existence of such a large body of explicitly encoded knowledge indicated that there existed a sufficient foundation upon which a knowledge-base could be constructed. It is a disadvantage from the point of view of user acceptance because, given the current state of development of the knowledge base, it is not immediately apparent to maintenance personnel that IFDIS would be any more useful than the original documentation. The only apparent advantage enjoyed by the current version of IFDIS over some other documentation systems, which have been disparagingly referred to as electronic page-turners, is the provision of explanations of the reasoning behind the current line of inquiry. It is probable that if the WP's had not existed and the same information had been extracted from the available maintenance personnel and other domain experts, then the current IFDIS would be seen as a significant achievement. The addition of capabilities which will allow IFDIS to collect and analyse data automatically will, of course, provide assistance to maintenance personnel which no documentation system alone can provide.

Chapter 5

Prototype development

The version of IFDIS developed to date is experimental. A prototype version will require an expansion of the scope of the knowledge-base along with attention to human interface quality. During the construction of this experimental version, a number of lessons have been learned which should aid the implementors of a prototype version of the system.

It is proposed that the prototype system utilise both forward- and backward-chaining to provide flexibility for the utilisation of both automatically-recorded and user- supplied data. As far as is practicable, as much use of the automatically recorded data should be made before the maintenance personnel are asked to perform any tests. This consideration might mean that some of the recommended tests are applied in an order which differs from that specified in the WP's. For instance, if a test result can be obtained from an automatic device very quickly and cheaply then perhaps such a test should be performed before even simple visual checks by the maintenance personnel.

It seems that the quality of the user interface could be crucial in determining the acceptability of the system. Since the interface will be so important, a number of configurations might possibilty be evaluated. The evaluation could proceed by having a variety of interfaces working with the same knowledge-base as far as possible. Maintenance people could be requested to use and comment upon the various interfaces available. If it is not possible to evaluate a number of configurations in parallel, it is suggested that the user interface consist of a good-quality graphics screen combined with a mouse-based interaction paradigm. Only passive graphics of diagrams from the manuals which can be accessed as required would be provided.

It is suggested that the prototype system use the WP documentation as a starting-point for the knowledge-base. The knowledge inherent in these manuals would require restructuring, modification and supplementing so that the quality of explanations could be enhanced. The prototype system should utilise a knowledge-base of the symptom-conclusion type with no attempt made to incorporate deeper-level reasoning capabilities at this stage. The WP's give no guidance on the course to be followed if the answer to a question is unknown. Domain experts will need to provide an indication of the situations in which data might not be available and the action to be taken in such situations. It may also become apparent that domain experts are actually making extensive use of reasoning under uncertainty rather than using the strictly categorical methods specified in the WP documentation.

It must be possible for users of the system to pass comments and suggestions on to the Knowledge Engineer when new situations not catered for by the knowledge-base arise or when new techniques are developed or errors are found. In the situation where IFDIS systems are in use at widely separated sites, the transfer of such comments and suggestions to a knowledge engineer located at a central site could perhaps be achieved via messages forwarded by an electronic mail system. Users could submit comments from within the consultation as the need arises and such comments could be forwarded, together with sufficient information on the context within which the comment was made for the Knowledge Engineer to decide on any necessary changes to the knowledge-base. Many commercially available shells provide facilities for the capture of user comments but the interfacing of the shell to an electronic mail system would require extra work.

Opportunistic redirection of the consultation will also be required. The user should never be required to answer questions that they know to be irrelevant. As an extreme example of the necessity for this, consider the case where the maintenance person is attempting to determine why the engine is not developing full power. If the engine suddenly bursts into flames and the fire is successfully quelled it is unlikely that a continuation of the attempt to improve the performance of the engine will be attempted. The need for the user to redirect the consultation might also arise if, during a test or inspection recommended by the Expert System to check on the correctness of an hypothesis which seems to explain the failure, another problem is noticed that would explain the observed fault, then the user should be able to volunteer this information and should not be asked questions which are now irrelevant. The Expert System should then check all available information to confirm that the cause of the problem has been found. If the evidence supplied to support the user's conclusion was not conclusive, the Expert System should be able to suggest further tests which could confirm the diagnosis. A full mixed initiative dialogue is what would ultimately be aimed for with control of the dialogue alternating between User and Expert System as appropriate.

A major emphasis of the prototype IFDIS should be to demonstrate the potential for integration of data from a variety of sources. The sources used by the prototype should be those which do not require realtime recording by the IFDIS system itself. Complications arising from the transfer of data between IFDIS and data sources, such as CAMM, might be reduced if an interface file is used to minimise the amount of direct interaction between systems. The provision of a prototype system which allows for the coherent utilisation of data from a number of sources will demonstrate that IFDIS does offer an advantage over the traditional methods and should contribute to user acceptance.

Chapter 6

Proposed extensions

Considerable systems for computerised support for maintenance of the F/A-18 aircraft already exist. The Computer Aided Maintenance Management (CAMM) part tracking system and Maintenance Data and Service Life Monitoring System (MD&SLMS) supported by the Unit Computing Facility (UCF) within each maintenance unit could provide valuable input to the IFDIS system. The ready availability of the data from the UCF should help to minimise the amount of manual troubleshooting which has to be performed on the ground (see Appendix B for an analysis of the primary sources of answers to various questions). Maintenance Signal Data Recording Set (MSDRS) data, which includes the IECMS data, is currently collected on the UCF and access to this data will be very important for development of the full capability for analysis of all data which is relevant to the maintenance function. The exact use which will be made of the auxiliary data has not yet been determined. Actual and potential uses will need to be investigated in collaboration with Australian personnel because the American documentation so far sighted makes no reference to such auxiliary data.

At this stage, it is envisaged that IFDIS will have access to UCF, and thereby CAMM and MD&SLMS, as well as CDU and AFTA via communication links.

The F/A-18 has an In-flight Engine Condition Monitoring System (IECMS) which can be used to record the values for various engine parameters. Recording by IECMS is initiated whenever the value of one of the engine parameters exceeds pre-set limits or when requested by the pilot of the aircraft who pushes a button to indicate that recording should commence. The data provided by IECMS is useful during attempts to troubleshoot the engine on the ground after a fault has been reported. Pre and post-events records provided by IECMS can be evaluated to provide a limited history of the behaviour of the engine before and after the incident. Another record, the Flight Incident Record, provides information on the operation of the aircraft and engines throughout the flight. Relationships between the recorded values of various engine parameters can often give clues to the environment within the engine during the incident that will aid in hypothesising a chain of events that could explain the observed behaviour of the engine. Comparisons between parameter values from each of the engines can be useful in deciding if the problem might have been due to atmospheric anomalies, the result of the operation of the aircraft (e.g. manoeuvreing) or whether the problem is confined to a malfunction within one engine.

The CAMM system will provide histories for each of the components and modules which comprise the engine. Using data such as the history of a particular main fuel control unit for instance, it will be possible to alter the diagnostic strategy for an engine using a particularly troublesome main fuel control unit to, perhaps, investigate the correct operation of this component earlier in a troubleshooting session than would otherwise be the case. Such an alteration of strategy could be achieved by having meta-rules which detect the presence of any historically troublesome modules and investigate them first. For such alterations of strategy to be feasible, it will be necessary to have modular descriptions of investigations to check the correct operation of particular modules so that sensible sequences of tests can be specified. Causal models of the operation of the engine or comprehensive knowledge provided by domain experts would be necessary to support more sophisticated reasoning behind reordering of tests and rules. Data from CAMM will also indicate the particular version or model of each component in the engine and it may be necessary to modify the troubleshooting strategy depending on the idiosyncracies of particular equipment models.

Given access to the CAMM system, it should also be possible to maintain a watch on the frequency with which various components fail and to use such data to alter the order in which questions are asked during the consultation if a particular type of component is found to be failure-prone.

The remarks above concerning reordering of questions also apply here.

Automated test equipment could provide valuable input to IFDIS. The Control Diagnostic Unit (CDU) is an automated test unit which can be used to check that the Electrical Control Assembly (ECA) is functioning correctly. The availability of the CDU and other automated test equipment may lead to modification of the troubleshooting procedures in the WP's with time-cosuming, manual tests that were performed late in the troubleshooting procedure being replaced by equivalent tests performed early in the procedure by automated test equipment.

A number of the tests required by the fault-tree tables need real-time access to the engine while it is in operation. Readings such as Exhaust Gas temperatures and readings shown by various cockpit instruments are needed during troubleshooting. Some work has already been done with the use of real-time data for diagnosis [6] [9]. Presumably, substantial real-time software will be needed to provide access to this data. Such software might be run on the hardware which also runs IFDIS or could be on separate hardware. The AFTA system [13] can access information which is displayed on cockpit instruments - IFDIS may be able to communicate with AFTA although details of interfacing to this device are yet to be determined.

A greatly enhanced user interface is also planned. Other work ([10] [20]) has emphasised the need to make the quality of the user interface high so that it will be accepted by users and this is expected to also be important for the acceptance of IFDIS. One of the points raised by technicians in the work reported in [10] was that they felt that finding schematic diagrams relevant to the problem under investigation was a waste of time. A computer system which could efficiently and conveniently display diagrams relevant to a particular component or system of the engine would be necessary. The interface would probably take the form of diagrams of some type (probably stored on video disk), a mouse-driven screen interface and possibly a speech-synthesis unit for the guidance of the maintenance people while they are actually inspecting the engines. It might be possible to accept responses to synthesised questions via a speech-recognition unit since the consultation could be structured so that only simple answers would be required. The noisy environment in which the troubleshooting work is carried out may preclude the use of this last option however.

On-line statistics should allow for improvement to the system as experience is gained. A record could be kept of the frequency with which each piece of knowledge is invoked and the failure rates of the components. Questions pertaining to components that the statistics indicate fail relatively often can be introduced early in the the consultation so that the number of focusing questions required for the most common types of failure is kept to a minimum. Such an update to the knowledge-base will normally be performed by the Knowledge Engineer maintaining the system.

The acquisition of the knowledge-base for IFDIS using manual techniques will be tedious to say the least. Automated knowledge acquisition would be extremely useful during the creation and augmentation of the knowledge-base. The procedures to be used in acquiring this knowledge would need much work to perfect and this could become a major direction of research for the IFDIS project. Some current work which could have relevance to this facet of the project are rule induction strategies of [14] and the work of Boose [2] with personal construct theory. It is expected that the initial knowledge-base will be constructed with the aid of engineering experts. A major source of the information which will be needed to improve the quality of the knowledge-base and the usability of IFDIS will , however, be the feedback obtained from the maintenance personnel using the system on a day-to-day basis.

The level of the consultation should match the level of sophistication of the user. A very experienced maintenance person and someone just out of training will require different levels of explanation and verbosity in prompts and explanations. The level of the interaction could be user selectable with dynamic variation of the level during the consultation. To determine an appropriate dynamic setting, the system could analyse the requests for elaboration and clarification by the user and try to automatically provide the appropriate level of verbosity for the remainder of the consultation. A particular user's level of expertise could be stored for recall in subsequent sessions.

The scope for incorporation of various types of models of the engine to aid maintenance personnel in evaluation of a particular engine seems to be wide. Such models could fall into two broad categories; quantitative and qualitative.

Quantitative models or simulations could be used to provide an analysis tool for predicting what values certain parameters should assume for particular control inputs. For example, given a particular throttle lever setting, temperature and altitude, predict the speed which the engine should reach. Such evaluations could be used to identify when the performance of a particular engine becomes marginal even though it still operates.

Since the results of some complex models can be extremely difficult to interpret, it may be necessary to provide a module within the expert system to aid the maintenance person in the interpretation of the results of the simulation.

Qualitative models should be able to provide the user with a tool for evaluating what if proposals - what if the electrical connection between the thermocouple harness and the main fuel control (if there is such a connection) were to become discontinuous ? What symptoms would be observable ? What tests would be appropriate to support or refute such an hypothesis ? The availability of such a qualitative model embodying connectivity of components, qualitative relationships between parameter values etc. should also provide a means for dramatic improvement in the quality of explanations provide to the user of the system. It is believed that models of this type are implicit in the fault trees but explicit specifications of them have not yet been obtained.

The incorporation of models which embody such deep knowledge of the problem domain is not yet well developed. A number of efforts are under way to determine the techniques which will be needed to support this type of reasoning about physical artifacts [8].

Chapter 7

An appropriate shell for IFDIS

It has become clear from the work already done that EMYCIN is not a suitable shell upon which to base a more ambitious version of IFDIS. The main deficiencies discovered in EMYCIN for the IFDIS task include a limited selection of representation formalisms, restricted inferencing strategies, no realistic support for mixed initiative dialogue and also implementation issues such as the need for a large mainframe and relatively poor quality of the code regarding maintainability. These latter implementation issues are, to some extent, surmountable with the purchase of a commercial implementation of an EMYCIN-like shell, a number of which are available (e.g S.1).

Given the current design expectations for the role and scope of IFDIS, it is expected that interfacing of the IFDIS to existing software will be required and the ability to interface to a number of different computer languages will also be useful when new, special purpose software is required for tasks such as simulation/modeling, communications with various hardware devices (e.g. CDU) and, perhaps high speed graphics.

The anticipated delivery environment will , of course, have a major impact on the choice of shell. Some of the currently available shells require special hardware support although there is a recent trend toward providing systems which can be delivered to the end-user using more widely available and cheaper hardware such as PC's. Some systems require specialised hardware to support the development environment but allow for delivery systems to run on PC's, perhaps using a larger mini for execution of the computation-intensive components of the software.

It seems certain that the shell selected for the implementation of IFDIS will need to exhibit the following features :-

- • forward chaining, backward chaining and the facilities for incorporation of user-written inference strategies
- • a good representation for procedural knowledge which can be in a format which is easily understood by the user (i.e will NOT be displayed in raw LISP)
- • access to the base-language of the shell such as LISP, Prolog etc.
- • a rich set of representation methods - e.g. frames, rules and logi
- • support for reasoning under uncertainty (probably)
- • non-monotonic logic support - perhaps via multiple worlds (as in KEE) that competing hypotheses can be concurrently investigated
- • graphics capabilities - perhaps only require ability to display st raster images which are stored on disk
- • interface capabilities - call routines written in different languages - run on hardware which can be interfaced to testing equipment
- • good knowledge-base construction and maintenance facilities
- • adequate performance re. response time when manipulating the large knowledge-base which will be required
- • support for a range of levels of user expertise via prompts and explanations of a suitable level of sophistication

Chapter 8

Acceptance of IFDIS by users

A number of issues will contribute to the acceptance of the system by users. Quality of the user interface will be extremely important and should be considered from the stand point of convenience and ease of use. Users are much more likely to accept the new system if it has obvious benefits over the old way of doing things. The role which the new system might play in the maintenance environment will also be important and will determined by the plan for a Maintenance Information Management System which is being developed by the RAAF.

A number of workers have stressed the importance that an acceptable user interface has in determining the success of expert systems and other types of computer systems also. It is extremely unlikely that a computer system whose user interface is clumsy and inefficient will be accepted for everyday use irrespective of the potential benefits which its use may bring. The issues involved in interface design are considered in more detail in [17].

The potential form which the user interface could assume is flexible. The availability of equipment to support input/output devices such as mice, light-pens, voice recognition and synthesis units and high quality bit-mapped graphics displays provides a wide choice of possibilities. The final choice may be determined largely by the environment in which IFDIS may be required to operate. Situations in which the level of background noise is high (e.g. a large hangar) could make the use of voice recognition input problematical. The lack of a convenient desk-top at a field location could make the use of a mouse inconvenient.

During a trip to Williamtown, some of the maintenance personnel were asked about their expectations of what the user interface could look like. It seems that the computer systems which they have so far encountered (primarily the CAMM system) are oriented toward typing and text. Given this type of prior experience of computer systems, more modern mouse/icon oriented interfaces as exemplified by the Apple Macintosh computer, should be acceptable. Most of the more well-developed systems described in the literature (e.g [7]) have a good-quality graphical interface on which a representation of the deduction path being followed and schematics of the system etc. can be displayed. Such interfaces require a large development effort but should contribute positively to acceptance and ease of use.

The flexibility of control of the direction of the dialogue will also affect the user's perception of the convenience of the interaction. The user should be able to volunteer as much information as possible to indicate the area of investigation in which they are interested. The EMYCIN system is not good in this respect since it is extremely difficult, if not impossible to volunteer information in a realistic manner - you are restricted to answering the questions posed to you by the system in the order determined by the system and not in the order which may be more convenient for you. An indication of a more flexible system for the sequencing of input can be seen in the report by Slagle et. al. [19].

It is expected that IFDIS will be routinely consulted by maintenance personnel when a problem arises. The role which IFDIS will fill and it's relationship to the job perception of the maintenance personnel will be extremely important. IFDIS will be used as an advisor/intelligent assistant and maintenance personnel will be encouraged to retain responsibility for the diagnosis. The benefits of using IFDIS should be such that it becomes just another tool in the maintenance toolbox. Having the power of a computer to help in the location of relevant information and to suggest alternatives to help the maintenance personnel from concentrating too early on one specific possible cause of a failure will be an advantage. The system should also be able to suggest further tests which can confirm a diagnosis so that the maintenance staff can be more confident that the real cause of the problem has been located. IFDIS should be perceived to be an intelligent assistant or advisor rather than a system which will do all the intelligent decision making during the maintenance action.

Chapter 9

Conclusion

The potential benefits of developing a full IFDIS seem to be appreciable. A large amount of further work will be required to fully realise the potential of such a system. It will be necessary to involve personnel from the manufacturer and other services with experience in maintenance of the F404 engine so that the results of their experience can be included in the system. Experience with the procedures specified in the fault-tree tables and proposals for shortcuts, explanations of reasoning etc. should be provided by personnel with everyday experience with the task at hand. Consultations with Australian personnel, and evaluation by them of a range of possible interface configurations to determine the appropriate form which the user interface might take will also be essential. A great deal of interfacing work to other computer systems will also be necessary. Experts in the use of the CAMM system will need to be consulted to determine the extent to which the CAMM data can be utilised and to give indications of ways in which IFDIS might be used to control updates of the CAMM system with information from current diagnostic attempts. Data on parts replaced etc. could be gathered by IFDIS in the course of the consultation and update instructions sent to the CAMM software as part of the diagnostic consultation. This type of interaction between CAMM and IFDIS will depend on IFDIS being routinely used in all diagnoses.

Incorporation of models of various types will require further investigation. Some quantitative models of various aspects of the engine's operation are already available but would probably need to be converted to run on different hardware to be suitable for delivery to field units. The development of qualitative models will require further research.

The form of the delivery system will need to be analysed. In certain circumstances, it is important that the system should be portable so that it can be taken into the field. Use in a field environment will raise difficulties since problems with communication to the UCF will result. Use of radio-based data communications may partially alleviate this problem but it will probably be necessary to ensure that IFDIS can operate adequately in a degraded mode if access to the databases such as CAMM is not available.

The investigations undertaken using EMYCIN indicate that it should be feasible to construct a useful aid for troubleshooting of problems in the F404 engine. It will be necessary to modify and supplement the knowledge contained in the fault tree tables to improve the comprehensibility of the system to maintenance personnel. Different inference strategies to those provided by EMYCIN will be required to handle the automatically recorded data and to cope with mixed- initiative dialogue. The need to deal with uncertain reasoning will probably also arise but has not been addressed in any depth yet. The question of the richness of the representation environment also will need further investigation when the type of knowledge which is to be incorporated into the system becomes clearer.

References

1. U. Bonollo and M. P. Georgeff, PERITUS- A system that aids the Construction of Procedural Expert Systems, Monash University, Department of Computer Science, August 1983.

2. J. H. Boose, A knowledge acquisition program for expert systems based on personal construct psychology, International Journal of Man-Machine Studies 23, (1985), 495-525.

3. Rule-based expert systems: the MYCIN experiments of the Stanford Heuristic Programming Project, , 1984.

4. B. G. Buchanan, Expert systems: working systems and the research literature, Expert Systems 3, 1 (January 1986), 32-.

5. J. Davison, J. B. Schroeder and R. Bell, Expert Systems Application for Flight Control Maintenance Diagnostics, in Proceedings of the 1984 Summer Computer Simulation Conference, vol. 2, Simulation Councils, Inc., 1985, 1235-7.

6. J. C. Esteva and R. G. Reynolds, A real-time knowledge based expert system for diagnostic problem solving, SPIE Applications of Artificial Intelligence 635, (1986), 97-105.

7. R. Fikes and T. Kehler, The Role of Frame Based Representation in Reasoning, Comm. ACM 28, 9 (Sep. 1985), 904-920.

8. P. K. Fink, J. C. Lusth and J. W. Duran, A General Expert System Design for Diagnostic Problem Solving, IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-7, 5 (September 1985), 553-60.

9. M. S. Fox, S. Lowenfeld and P. Kleinosky, Techniques for Sensor-Based Diagnosis, in Proceedings of the Eighth International Joint Conference on Artificial Intelligence 8-12 August 1983, Karlsruhe, West Germany , vol. 1, A. Bundy (ed.), William Kaufmann, Inc., Los Altos, 1983, 158-163

10. M. Freiling, J. Alexander, S. Messick, S. Rehfuss and S. Shulman, Starting a Knowledge Engineering Project: A Step-by-Step Approach, AI Magazine 6, 3 (Fall 1985), 150-64, AAAI.

11. R. T. Gallagher, AI to Help Mechanics at Renault to Do a Better Job, Electronics 58, 50 (Dec. 16, 1985), 27.

12. M. Georgeff, An Interactive Fault Diagnosis and Isolation System for the F404 - F/A-18 Engine, , 1983.

13. P. Grad, Analyser checks F/A-18 for faults, Engineers Australia, , October 18, 1985, 31-2.

14. A. Hart, Knowledge elicitation: issues and methods, computer-aided design 17, 9 (November 1985), 455-62.

15. H. E. Johnson and P. P. Bonissone, Expert System for Diesel Electric Locomotive Repair, The Journal of Forth

Application and Research 1, 1 7-16.

16. G. Kahn and J. McDermott, MUD: A Drilling Fluids Consultant, Carnegie Mellon University Department of Computer Science, Mar. 1985.

17. A. L. Kidd and M. B. Cooper, Man-machine interface issues in the construction and use of an expert system, International Journal of Man-Machine Studies 22,

(1985), 91-102, Academic Press Inc. (London) Limited.

18. T. J. Laffey, W. A. Perkins and T. A. Nguyen, Reasoning About Fault Diagnosis with LES, IEEE Expert, , Spring 1986, 13-20.

19. J. R. Slagle and H. Hamburger, An Expert System for a Resource Allocation Problem, Comm. ACM 28, 9 (Sep. 1985), 994-1004.

20. R. G. Smith and J. D. Baker, The Dipmeter Advisor System - A Case Study in Commercial Expert System Development, Proceedings of the Eighth International Joint Conference on Artificial Intelligence 1, (1983), 122-9, William Kaufmann.

21. W. Van Melle, A. C. Scott, J. S. Bennett and M. Peairs, The Emycin Manual, STAN-CS-81-885, Department of Computer Science, Stanford University, October 1981.

22. A. J. Wilkinson, MIND: An Inside Look at an Expert System for Electronic Diagnosis, IEEE Design & Test of Computers, August 1985, 69-77.

	No	Yes
a. During no start attempt, did fan and compressor rotate?	c	b
b. Do substeps below:		
(1) In left and right main landing gear wheelwell, observe fuel valves manual shutoff arms.		
(2) Is engine fuel shutoff valves manual shutoff arms in the CLOSED position?	e	v
c. Do substeps below:		
(1) Open door 65 L or R (A1-F18AC-LMM-010)		
(2) Can compressor be rotated by turning power transmission shaft by hand?	o	d
CAUTION		
Move through engine inlet duct carefully to prevent damage to vortex generators on lower surface midway down duct		

d. Do substeps below:

.
.
.
.
.

Fig 1. Example of Fault-Tree table
(extracted from A1-F18AC-270-200 WP005 00 page 3)

RULE003

[This rule is tried in order to find out about whether the stall is the result of a fuel problem]

If: 1) The main fuel control density setting does not match the type of fuel in the aircraft,
2) There was indication of an impending fuel bypass, or
3) The compressor discharge pressure line (ps3) is broken

Then: It is definite (1.0) that the stall is the result of a fuel problem

Fig. 2. Example of an IFDIS rule

```
RULE083
-------
[This rule is tried in order to find out about the conclusion]

  If:  1) You have examined maintenance status display and recording
          system maintenance codes, and have found one for which
          A: It is 709, or
          B: It is 759, and
       2) A: The data obtained from the signal data recording set
             does seem bad,
          B: Boroscope inspection reveals that the hot section is not
             within limits,
          C: Signal data recording set AN/ASM-612 magnetic tape
             cartridge engine data did show engine INLET TEMP
             exceeded 38C when maintanance code 709 or 759 was set,
          D: The engine has an fod problem as defined in wp7
             table1,
          E: More than 2.0vdc does exist for the measurement
             specified in question n table 1 wp007 0,
          F: After starting both engines and with both engines at
             ground idle there is more than 5c difference between
             left and right inlet temp, or
          G: There is a problem with the ven positioning or position
             reporting mechanisms
  Then:  It is definite (1.0) that the following is the conclusion:
             PROBLEM SOLVED
```

Fig. 3 A rule with a large number of premises

Appendix A - A sample run of the IFDIS consultant

All user responses appear on lines which begin with "**". The lines containing text enclosed in braces (i.e. "{" and "}") are used as reference points in the body of the report.

```
5:33PM in <EXT.ARL>EMYCIN.EXE.3 by EXT.ARL

Recording on <EXT.ARL>TYPESCRIPT.JENGINE.4

Rules, Parms, Go, etc. : Go
Special options (type ? for help):
**
---------------------------------------------------------------------

24-Jan-86 17:33:46

   --------JENGINE-2--------
   1) what type of start failure was it?
   ** ?
   What is start failure type?
   Expected responses are: NO-START, STALL or HOT
   Enter HELP for list of user options.
   ** NO-START
   2) What is serial number?
   ** 1234
   3) Did during the no start attempt, the fan and compressor rotate?
   ** YES
   4) Were the manual shutoff arms of the main fuel control valve in
      the closed position?
   ** WHY

[i.e. WHY is it important to determine whether the manual shutoff
     arms of the main fuel control valve were in the closed position?]

[1.0] This will aid in determining the conclusion.
     It has already been established that
        [1.1] start failure type is no-start
     Therefore, if
        [1.2] 1) There is a mechanical problem,
              2) The manual shutoff arms of the main fuel control valve
                 were in the closed position,
              3) There is a problem with the igniters, or
              4) There is a problem with the fuel supply or
                 distribution system
     then
        it is definite (1.0) that the following is the conclusion:
           PROBLEM SOLVED
     [ALSO:
        display the recommended action]
     [RULE032]

   [back to question 4...]

   ** ?
   Were the manual shutoff arms of the main fuel control valve in the
   closed position?
   Expected responses are: YES or NO
   Enter HELP for list of user options.
   ** NO
   5) Does the main igniter fire 2 to 3 times per second while the
      engine is motoring?
   ** YES
   6) Does continuity exist with throttle at ground idle?
   ** WHY                                                          {A}

[i.e. WHY is it important to determine whether continuity does exist
     with throttle at ground idle?]

[2.0] This will aid in determining whether there is a problem with
     either the throttle or the main fuel pump.
     If
        [2.1] 1) Continuity does exist with throttle at ground idle,   {A1}
              2) Continuity does not exist with throttle off, or
              3) Fuel vapors do not come from the exhaust when throttle
                 is advanced during start, and
        [2.2] the throttle rig pin was easily installed with the
                 throttle at mil, and
```

```
         [2.3] the main fuel pump spline did rotate when the power
                   transmission shaft was turned
      then
         it is definite (1.0) that there is a problem with either the
            throttle or the main fuel pump
      [RULE066]

    [back to question 6...]
    ** HOW 2.2                                                         {B}

[i.e. HOW is it determined whether the throttle rig pin was easily
      installed with the throttle at mil?]

      There are no rules which allow the deduction of whether the
      throttle rig pin was easily installed with the throttle at mil,
      so a question will have to be asked.

    [back to question 6...]
    ** ?
    Does continuity exist with throttle at ground idle?
    Expected responses are: YES or NO
    Enter HELP for list of user options.
    ** YES
    7) Was the throttle rig pin easily installed with the throttle at
       mil?
    ** YES
    8) Did the main fuel pump spline rotate when the power
       transmission shaft was turned?
    ** WHY
[i.e. WHY is it important to determine whether the main fuel pump
      spline did rotate when the power transmission shaft was turned?]

[3.0] This will aid in determining whether there is a problem with
      either the throttle or the main fuel pump.
      It has already been established that
         [3.1] continuity does exist with throttle at ground idle, and
         [3.2] the throttle rig pin was easily installed with the
                   throttle at mil
      Therefore, if
         [3.3] the main fuel pump spline did rotate when the power
                   transmission shaft was turned
      then
         it is definite (1.0) that there is a problem with either the
            throttle or the main fuel pump
      [RULE066]

    [back to question 8...]
    ** HOW 3.2

[i.e. HOW was it established that the throttle rig pin was easily
      installed with the throttle at mil?]

In answer to question 7 you said that the throttle rig pin was easily
      installed with the throttle at mil.

Thus, it has been established that the throttle rig pin was easily
      installed with the throttle at mil.

    [back to question 8...]
    ** ?
    Did the main fuel pump spline rotate when the power transmission
    shaft was turned?
    Expected responses are: YES or NO
    Enter HELP for list of user options.
    ** YES
         REPLACE MAIN FUEL CONTROL - WP008 00.
    9) Do give the chance to go back and change an answer to explore a
       different path through the tree?
    **
    ** NO


Enter Debug/review phase, or other option (? for help) :

Rules, Parms, Go, etc. : Typescript
Closing typescript file:<EXT.ARL>TYPESCRIPT.JENGINE.4
```

The following tables indicate the primary source of information which will be required to answer a question. Where data has been gathered automatically, it should not be necessary for this data to be manually transcribed but instead the data should be collected directly by the IFDIS system. Questions which are essentially recommendations for specific maintenance actions to be performed are indicated by '-' as primary information source.

Primary information sources for WP007 00 Table 1.

Question	Source
a	MMP code from IECMS
b	pilot incident report (EE500)
c	-
d	indication from UCF
e	from UCF
f	maintenance personnel
g	from UCF
h	maintenance personnel
i	UCF
j	UCF
k	maintenance personnel
l	" "
m	-
n	CDU or ground test
o	-
p	real-time hookup
q	Maintenance personnel/CDU
r	" "
s	real-time hookup
t	" "
u	" "
v	maintenance personnel
w	CDU or ground test
x	"
y	"
z	"
aa	"
ab	"
ac	-
ad	CDU or ground test
ae	-
af	CDU or ground test
ag	-
ah	-
ai	CDU or ground test
aj	-
ak	CDU or ground test
al	-
am	maintenance personnel
an	" "
ao	" "
ap	-
aq	-
ar	maintenance personnel
as, at, au, av, aw, ax, ay	-

Primary information sources for WP007 00 Table 2

Question	Source
a	real-time hookup
b	" "
c	" "
d	" "
e	" "
f	" "
g	" "
h	" "
i	maintenance personnel
j	" "
k	-
l	CDU or ground test
m	"
n	-
o	-
p	-
q	CDU or ground test
r	"
s	"
t	"
u	-
v	-
w	maintenance personnel
x	" "
y	CDU or ground test
z	"
aa	-
ab	maintenance personnel
ac	" "
ad	" "
ae	CDU or ground test
af	"
ag	-
ah	-
ai	-
aj	CDU or ground test
ak	"
al	-
am	-
an	-

Primary information sources for WP007 00 Table 3.	
Question	Source
a	CDU or ground test
b	real-time hookup
c	maintenance personnel
d	" "
e	CDU or ground test
f	"
g	maintenance personnel
h	real-time hookup
i	maintenance personnel
j	-
k	-
l	-
m	CDU or ground test
n	"
o	"
p	"
q	-
r	-
s	-
t	-
u	-
v	-
w	CDU or ground test
x	CDU or ground test
y	-
z	CDU or ground test
aa	-
ab	CDU or ground test
ac	-
ad	-

X

DISTRIBUTION

AUSTRALIA

Department of Defence

Defence Central
- Chief Defence Scientist
- AS, Science Corporate Management (shared copy)
- FAS Science Policy (shared copy)
- Director, Departmental Publications
- Counsellor, Defence Science, London (Doc Data Sheet Only)
- Counsellor, Defence Science, Washington (Doc Data Sheet Only)
- OIC TRS, Defence Central Library
- Document Exchange Centre, DSTIC (18 copies)
- Joint Intelligence Organisation
- Librarian H Block, Victoria Barracks, Melbourne

Aeronautical Research Laboratory
- Director
- Library
- Chief - Flight Mechanics and Propulsion Division
- Head - Propulsion Branch
- Branch File - Propulsion
- Author: M.D. Larkin - Deakin University
  - D.A. Frith
  - A.S. Finlay

Materials Research Laboratory
- Director/Library

Defence Science & Technology Organisation - Salisbury
- Library

Air Force Office
- Air Force Scientific Adviser
- Director General Engineering - Air Force
- Headquarters Logistic Command
  - AIRENG2
  - AIRENG2A
- CO No 482 Squadron
- CO No 3 Squadron
- CO No 3 Aircraft Depot
- CO No 2 Operational Conversion Unit

Universities and Colleges

- Deakin University
  - Professor J.G. Wallace

SPARES (10 COPIES)
TOTAL (42 COPIES)

AL 149 DEPARTMENT OF DEFENCE

DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER	1b. ESTABLISHMENT NUMBER	2. DOCUMENT DATE	3. TASK NUMBER
AR-004-515	ARL-PROP-TM-439	JANUARY 1987	AIR86/031

4. TITLE
IFDIS - AN EXPERT SYSTEM FOR DIAGNOSIS OF FAILURES IN JET AIRCRAFT ENGINES

5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), UNCLASSIFIED (U)).

DOCUMENT	TITLE	ABSTRACT
U	U	U

6. NO. PAGES
40

7. NO. REFS.
22

8. AUTHOR(S)
M.D. Larkin - Deakin University
D.A. Frith
A.S. Finlay

9. DOWNGRADING/DELIMITING INSTRUCTIONS

Not applicable

10. CORPORATE AUTHOR AND ADDRESS

AERONAUTICAL RESEARCH LABORATORY

P.O. BOX 4331, MELBOURNE VIC 3001

11. OFFICE/POSITION RESPONSIBLE FOR:
SPONSOR RAAF
SECURITY -
DOWNGRADING -
APPROVAL -

12. SECONDARY DISTRIBUTION (OF THIS DOCUMENT)

Approved for public release.

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DSTIC, ADMINISTRATIVE SERVICES BRANCH, DEPARTMENT OF DEFENCE, ANZAC PARK WEST OFFICES, ACT 2601

13a. THIS DOCUMENT MAY BE ANNOUNCED IN CATALOGUES AND AWARENESS SERVICES AVAILABLE TO ....

No limitations

13b. CITATION FOR OTHER PURPOSES (IE. CASUAL ANNOUNCEMENT) MAY BE [X] UNRESTRICTED OR [ ] AS FOR 13a.

14. DESCRIPTORS
Expert systems
Fault analysis
Jet engines
Engine failure
Aircraft maintenance

15. DISCAT SUBJECT CATEGORIES

0081D

16. ABSTRACT
IFDIS (Interactive Fault diagnosis and Isolation System) is being developed to aid in the isolation of faults in the F404 jet engines that are installed in the F/A-18 fighters. Existing documentation supporting troubleshooting for these engines is inflexible in the level of sophistication expected of the user and it does not explicitly use the reasoning with uncertain information which is inherent in human troubleshooting. Data, which is required for troubleshooting the F404, is currently or potentially available for computer processing from a number of sources. IFDIS will assist maintenance personnel by providing on-line access to relevant information and will perform much of the tedious interpretation of the available data. The expert knowledge embodied in some of the existing maintenance manuals has been re-expressed in a format that serves as the basis for the knowledge-base for an expert system.

PAGE CLASSIFICATION
UNCLASSIFIED
PRIVACY MARKING

THIS PAGE IS TO BE USED TO RECORD INFORMATION WHICH IS REQUIRED BY THE ESTABLISHMENT FOR ITS OWN USE BUT WHICH WILL NOT BE ADDED TO THE DISTIS DATA UNLESS SPECIFICALLY REQUESTED.

16. ABSTRACT (CONT).

Expert system techniques have been employed because they offer benefits of perspicuity, they can be developed incrementally and can cope with imprecise data. IFDIS is currently based on EMYCIN but will be reimplemented using a commercial expert system shell in the near future.

17. IMPRINT

AERONAUTICAL RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. COST CODE	20. TYPE OR REPORT AND PERIOD COVERED
AIRCRAFT PROPULSION TECHNICAL MEMORANDUM 439	47 3541	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF (S)

23. ADDITIONAL INFORMATION (AS REQUIRED)